Hydrogeologic Controls on Salt Domes in Coal Strip Mine Spoils

Report No. 175

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WATER RESOURCES CENTER

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by

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HYDROGEOLOGIC CONTROLS ON SALT LOADS IN STRIP MINE SPOILS

By

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ABSTRACT

Coal strip-mining is a process by which coal is removed and the spoils-material is deposited behind an advancing pit. As this coal, and subsequently the spoils-material, are often the principal aquifers for the area, the influence of the mine on ground-water flow and water-quality is of particular concern. The objective of this investigation was to compile existing data obtained by mining companies, the Montana Department of State Lands, and the Montana Bureau of Mines and Geology in order to address these concerns.

A common method of calculating the flow of ground water to an open pit is to use a series of equations based on a line-sink for the long side of the pit and a circular-sink for the ends of the pit. The first phase of the investigation was to find an alternative method. A method was developed that utilizes a single equation to predict the drawdown in a well at a given distance from a linear pit. In addition to distance, the equation is based on the hydraulic conductivity of the aquifer material, the discharge rate from the pit, and the length of the pit. A comparison was then made between calculated values using this equation and those calculated by a computer-generated, finite-element model.

The second phase of the investigation was to determine a statistical relationship between the ground water transmitting capacity of the spoils-materials and water-quality. Existing data were obtained for three mines in eastern Montana. A statistical analysis of the total dissolved solids and transmissivity data for each mine was conducted. After performing several data transformations, the available data indicated little or no correlation between the two parameters. Subsequent comparisons of data from all three mines indicated the same lack of correlation between transmissivity and TDS. The analyses suggest that while transport of salts may be controlled by such parameters as transmissivity, the loading rate is a function of the unsaturated zone parameters and the availability of salt.

Hydrogeologic Controls on Salt Loads in Coal Strip Mine Spoils

John J. Metesh

INTRODUCTION

Coal strip-mining is a process by which coal is removed and the spoils-material is deposited behind an advancing pit. As this coal, and subsequently the spoils-material, is often the principal aquifer for the area, the influence of the mine on ground-water flow and water-quality is of particular concern. The objective of this investigation was to compile existing data obtained by mining companies, the Montana Department of State Lands, and the Montana Bureau of Mines and Geology in order to address these concerns.

Although the relationship between solute transport and ground-water flow can be established under most conditions, in the case of coal spoils, this is not always the case. As the mine pit progresses, water level, lowered by pumping and draining of the coal aquifer, immediately begins to be re-established in the new spoils. The physical and chemical characteristics of this new aquifer may be much different than that of the pre-existing coal and overburden. As saturation of the spoils occurs, ground water is in contact with material previously unsaturated and dissolved constituents are then available for transport. In order to address these issues, it becomes necessary to establish the effects of a long pit on ground-water flow. Subsequent to this, a relationship between the aquifer

characteristics and ground-water quality may also be established.

The most common method of calculating the flow of ground water to an open pit is to use a series of equations based on a line-sink for the long side of the pit and a point-sink for the ends of the pit. The calculation of hydraulic head distribution in the vicinity of a linear pit by these methods is generally not accurate. The two sets of equations fail to arrive at the same head value for common points in the aquifer. This is especially true for points located near the corner of the pit. In response to this, the first phase of the investigation was to find an alternative method. An equation was developed that utilizes a single equation to predict the draw-down in a well at a given distance from a linear pit. In addition to distance, the equation is based on the hydraulic conductivity of the aquifer material, the discharge rate out of the pit, and the length of the pit. A comparison was then made between calculated values using this equation and those calculated by a computer-generated, finite-element model.

The second phase of the investigation was to determine if a statistical relationship exists between the ground water transmitting capacity of the spoils-materials and water-quality. Existing water-quality and aquifer-test data were obtained for the Decker Mine, the Rosebud Mine, and the Big Sky Mine located in south-central Montana. A statistical analysis of the total dissolved solids (TDS) and transmissivity data for each mine was conducted.

FLOW TO OPEN PIT

Several methods have been used to predict the effects of pumping from long, narrow pits on ground water levels. One of the more common methods is to combine the equations for a line-sink (sides of the pit) and point sink (ends of the pit). However, the potentiometric surface generated by this method does not reflect realistic conditions near the pit.

In response to this, an alternative method was devised that would consider flow to both the sides and the ends of the pit in a single equation. The basis of this method lies in using an equation for a point sink and integrating the effects over the length of the pit. Although pit width is not taken into consideration, the effects of the pit on the sides and the ends are realistic.

This equation is thus derived:

The equation of an ellipse in standard position is used:

$$\frac{(X_1-X_2)^2}{a^2}+\frac{(Y_1-Y_2)^2}{b^2}=1 \qquad (1)$$

which can be further defined for this purpose as

$$\overline{F_1P}+\overline{F_2P}=2a \tag{2}$$

where:

2a: length of major axis (pit)

P: a given point on the ellipse (outside the pit)

F: focal points of the ellipse

The equation by Polubarinova-Kochina (1962) defines the change in potential (draw-down) in a porous medium of hydraulic conductivity K, at a distance D in response to a point-sink of magnitude dQ such that:

$$d(\Delta\Phi)=\frac{dQ}{4\pi KD} \tag{3}$$

which assumes an infinitely small well radius (r_w)

$$r_w \rightarrow 0 \tag{4}$$

for this application, the distance D is defined as the length of the line from a point within the pit to a given point P outside the pit:

$$\overline{D}=((X_2-X_1)^2+(Y_2-Y_1)^2)^{1/2} \tag{5}$$

Equations 4 and 5 are combined to yield:

$$d(\Delta\Phi)=\frac{dQ}{4\pi K(X_2-X_1)^2+(Y_2-Y_1)^2)^{1/2}} \tag{6}$$

with the coordinates of point P are given as

$$P=(X_2Y_1) \tag{7}$$

In order to produce a line-sink, dQ is distributed along the length of the pit (2a) by dividing the pit into line elements:

$$dQ=\frac{Q}{2a}d\epsilon \tag{8}$$

Thus equation 6 becomes

$$d(\Delta\Phi)=\frac{Q}{2a}\cdot\frac{1}{4\pi K((X_2-X_1)^2+Y^2)^{1/2}}d\epsilon \tag{9}$$

which can be integrated over the length of the pit from -a to a:

Simplifying the right side of equation 9

$$\int_{-a}^{a} d(\Delta\Phi) = \int_{-a}^{a} \frac{Q}{2a} \frac{1}{4\pi K((X_2-X_1)^2+Y^2)^{1/2}} d\epsilon \tag{10}$$

$$= \frac{Q}{8aK\pi} \int_{-a}^{a} \frac{1}{((X_2-X_1)^2+Y^2)^{1/2}} d\epsilon \tag{11}$$

and using the form

$$\int_{a}^{b} \frac{1}{U} du = \ln U \,|_{a}^{b} = \ln a - \ln b \tag{12}$$

yields

$$\Delta\Phi = \frac{Q}{8a\pi K} * \ln(a-X_2+((a-X_2)^2+Y^2))^{1/2}) - \ln(-a-X_2+((a-X_2)^2+Y^2))^{1/2}) \tag{13}$$

which simplifies to:

$$= \frac{Q}{8a\pi K} \ln\left(\frac{a-X_2+((a-X_2)^2+Y^2)^{1/2}}{-a-X_2+((a+X_2)^2+Y^2)^{1/2}}\right) \tag{14}$$

Since

$$D_1 = ((X+a)^2-Y^2)^{1/2} \tag{15}$$

and

$$D_2 = ((X-a)^2 - Y^2)^{1/2} \tag{16}$$

this further simplifies to:

$$\Delta\Phi = \frac{Q}{8a\pi K} \ln\left(\frac{2a+D_1+D_2}{-2a+D_1+D_2}\right) \tag{17}$$

where:

$\Delta\Phi$: drawdown at point P

Q: total discharge from pit

a: ½ length of pit

D_1 and D_2 : distances from end of pit to point P

Using the above equation, the drawdown caused by pumping of a long pit can be calculated at any point outside the pit given the relative X and Y coordinates, the hydraulic conductivity value of the effected aquifer, the discharge from the pit, and the length of the pit. Any set of consistent units may be used and the values calculated using a hand calculator or spreadsheet application program.

In order to verify the application of this equation, a computer generated flow model was constructed using a finite element model, TRAFRAP (Huyakorn, 1987), which will simulate flow

in fractured or porous media. For the purposes of this investigation, a single discrete fracture in a homogeneous, isotropic, porous medium was used. The "fracture" was used to simulate a long pit of finite length. Values for hydraulic conductivity and pit discharge are typical of those estimated for aquifers in south-central Montana. A rectangular grid of equal spacing was used to facilitate comparison of model calculated values to values calculated using the proposed equation. The input file for the computer generated model is presented in Appendix I along with a partial output including drawdown values generated by the model. A full output file from this particular model is quite large and, thus, was not included.

The same input for pit length, discharge, and hydraulic conductivity were used in the equation to obtain drawdown values. In order to simulate conditions within the pit, values determined to undefined by the equation were defined as equal to the nearest real value in the spreadsheet.

Selected values from each method are presented in Table 1. As can be seen by comparison of values at each point, there is generally good agreement between the two methods. In addition to this, the actual values calculated are very reasonable for the values used as input and correspond well to observed drawdown in aquifers adjacent to mine pits in south-central Montana.

As further comparison, cross-sections through the drawdown

TABLE 1
Comparison of TRAFRAP Flow Model Output
To Pit Flow Equation Output

X-COORD	Y-COORD	TRAFRAP DRAWDOWN	EQUATION DRAWDOWN
1000	1000	0.0010	0.0024
1000	2000	0.0018	0.0028
1000	3000	0.0023	0.0032
1000	4000	0.0029	0.0035
1000	5000	0.0029	0.0037
1000	6000	0.0030	0.0035
1000	7000	0.0024	0.0032
1000	8500	0.0014	0.0026
2000			
2000	1000	0.0017	0.0027
2000	2000	0.0028	0.0033
2000	3000	0.0040	0.0040
2000	4000	0.0050	0.0048
2000	5000	0.0054	0.0052
2000	6000	0.0050	0.0048
2000	7000	0.0040	0.0040
2000	8500	0.0020	0.0030
2000	10000	0.0010	0.0023
3000	1000	0.0021	0.0030
3000	2000	0.0037	0.0038
3000	3000	0.0055	0.0051
3000	4000	0.0079	0.0072
3000	5000	0.0087	0.0088
3000	6000	0.0079	0.0072
3000	7000	0.0055	0.0051
3000	8500	0.0029	0.0033
4000	1000	0.0025	0.0032
4000	2000	0.0042	0.0042
4000	3000	0.0066	0.0061
4000	4000	0.0121	0.0112
4000	5000	0.0121	0.0112
4000	6000	0.0121	0.0112
4000	7000	0.0066	0.0061
4000	8500	0.0030	0.0036
5000	1000	0.0024	0.0032
5000	2000	0.0043	0.0042
5000	3000	0.0067	0.0061
5000	4000	0.0103	0.0112
5000	5000	0.0103	0.0112
5000	6000	0.0103	0.0112
5000	7000	0.0066	0.0061
5000	8500	0.0033	0.0036

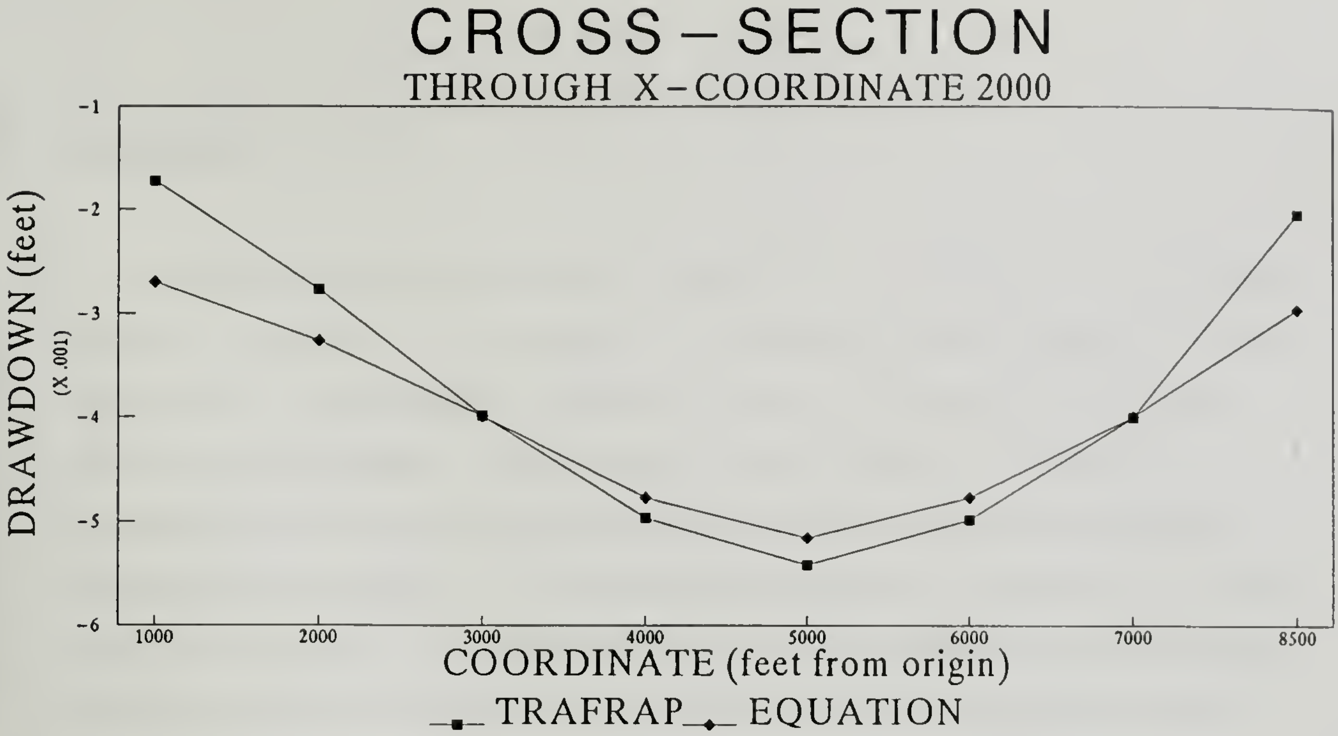
X-COORD	Y-COORD	TRAFRAP DRAWDOWN	EQUATION DRAWDOWN
6000	1000	0.0024	0.0030
6000	2000	0.0039	0.0038
6000	3000	0.0058	0.0051
6000	4000	0.0081	0.0072
6000	5000	0.0089	0.0088
6000	6000	0.0081	0.0072
6000	7000	0.0058	0.0051
6000	8500	0.0028	0.0033
7000	1000	0.0019	0.0027
7000	2000	0.0031	0.0033
7000	3000	0.0043	0.0040
7000	4000	0.0054	0.0048
7000	5000	0.0058	0.0052
7000	6000	0.0054	0.0048
7000	7000	0.0043	0.0040
7000	8500	0.0026	0.0030
8500	1000	0.0012	0.0023
8500	2000	0.0017	0.0026
8500	3000	0.0024	0.0029
8500	4000	0.0026	0.0031
8500	5000	0.0029	0.0032
8500	6000	0.0026	0.0031
8500	7000	0.0025	0.0029
8500	8500	0.0015	0.0024
10000	1000	0.0000	0.001873831
10000	2000	0.0008	0.0020
10000	3000	0.0000	0.0022
10000	4000	0.0012	0.0023
10000	5000	0.0000	0.0023
10000	6000	0.0013	0.0023
10000	7000	0.0000	0.0022
10000	8500	0.0013	0.0020

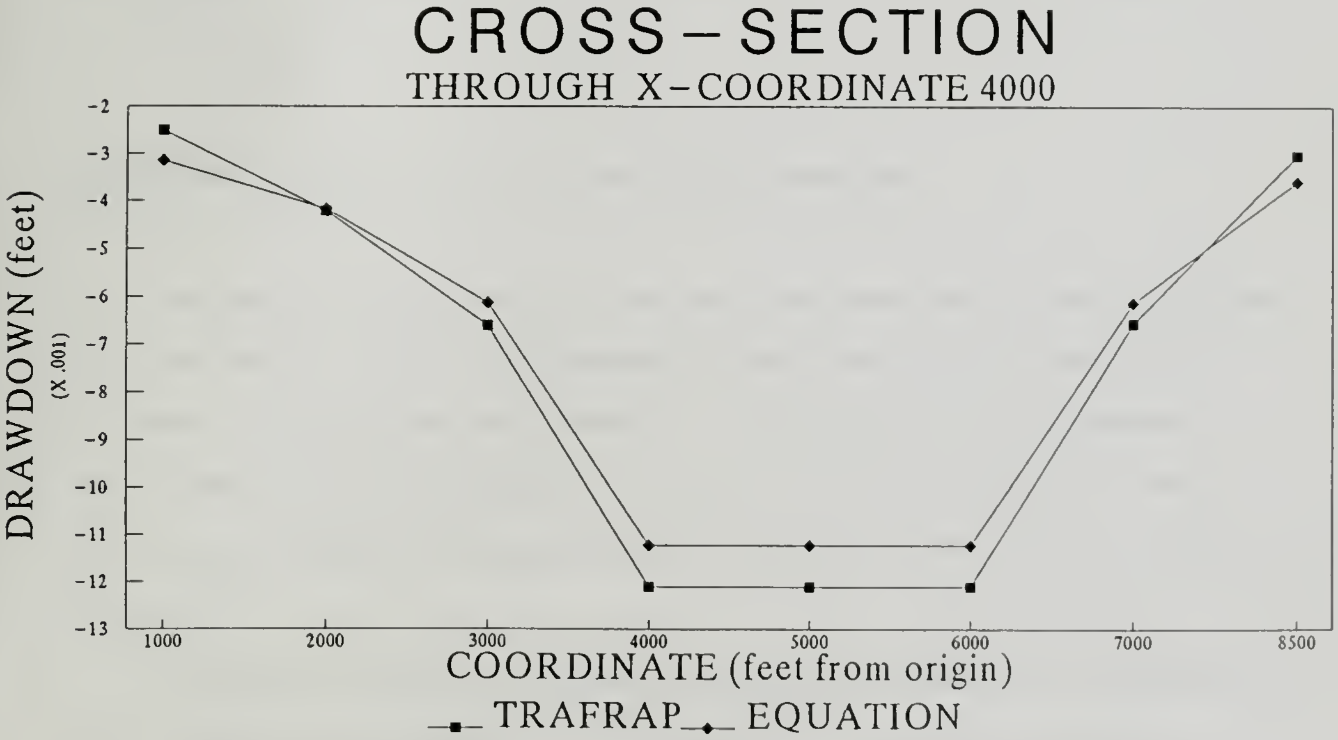
trough were constructed using values calculated from each method. These are presented in Figure 1. Once again, a reasonable comparison of values is evident. The largest difference in drawdown values occur at larger distances from the pit. As is inherent to computer generated approximations, those drawdown values near the default no-flow boundary of the model are likely to be higher.

The application of the equation is not limited to homogeneous media. In the case where the aquifer affected by the pit is not homogeneous, the equation can be especially useful. Values for drawdown can be calculated and will reflect the relative impact by the pit. This is particularly applicable in coal mine pits where the relative hydraulic conductivity of the undisturbed and the spoils material may be different.

Equations were not derived for isotropic conditions where hydraulic conductivity is not constant in two or three dimensions. As the equation and the application for which it is intended deals with the occurrence of drawdown on a large scale, anisotropy becomes less significant. This is particularly true in two dimensions.

A similar equation can be derived for confined flow by substitution of the appropriate equation for (3). The value calculated by the equation would represent the reduction of the potential caused by pumping from a long pit


CROSS-SECTION
THROUGH X-COORDINATE 2000
DRAWDOWN (feet)
(X .001)
-1
-2
-3
-4
-5
-6
1000
2000
3000
4000
5000
6000
7000
8500
COORDINATE (feet from origin)
TRAFRAP
EQUATION


CROSS-SECTION
THROUGH X-COORDINATE 4000
DRAWDOWN (feet)
(X .001)
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
1000
2000
3000
4000
5000
6000
7000
8500
COORDINATE (feet from origin)
TRAFRAP
EQUATION

Discussion

Examples of the behavior described by the equation are not readily available. In order to evaluate the application of the equation to large scale features, a small "bench scale" test should be performed. This would entail a long trench to be constructed in an area of shallow ground water and relatively homogeneous material. A significant number of observation wells would be required to record the effect of discharge from the pit on the surrounding aquifer. A single aquifer test should be required to evaluate the hydraulic conductivity of the material. The same data would be used to calculate the drawdown by the equation. A comparison of the results could then be made.

Mine Spoils Transmissivity and Water-quality

Existing water-quality and aquifer-test data were obtained for the Decker Mine, the Rosebud Mine, and the Big Sky Mine located in south-central Montana. Although a large number of wells have been installed in these areas, the number of well sites have both water-quality and aquifer transmissivity data was limited.

The intent was to evaluate the premise that salt loading by mine spoils was related to the ability of those spoils to

transmit ground water. The data for each mine area was transformed in a variety of ways and a statistical analysis of the total dissolved solids (TDS) and transmissivity data performed. These parameters were chosen as each represents a combined effect of a multitude of the respective factors involved.

The data for each site was plotted in arithmetic, semi-log, and log-log for each site. These plots are presented in Appendix II. Tables 2 through 5 are the listings of data used and the results of the statistical analyses for each mine site. The 'r' value, or correlation coefficient, for two best transformations are presented here. The degree of correlation indicates to what degree one population can attribute its variation to a second population. The theoretical value of 'r' ranges from +1 to -1 which indicate perfect fit with 0 representing no correlation. The Student's 't' statistic is also presented.

Table 2 is a listing of data and a summary of statistics for the Decker Mine spoils. The correlation coefficient for the arithmetic plot is the best at 0.442 with 12 observations. this is regarded as a relatively poor correlation.

In Table 3, data for the Rosebud Mine area, the best 'r' value obtained from the various transformations is 0.25 for the arithmetic plot. The number of observations for this analysis was only slightly more than that for the Decker Mine.

Table 4 is the data and analysis for the Big Sky Mine area. the correlation coefficient based on 10 observations was

calculated to be 0.36. As with the other sites, this was obtained with the arithmetic plot or no transformation.

Although not presented, other transformations of the data were performed as mentioned. However, for each set of data, the highest degree of correlation was obtained with no transformation of the data set.

Data from all three mine sites were combined and the same analysis performed (Table 5). In this case, the best correlation coefficient value, 0.32, was obtained with the plot of logarithmic transmissivity (T) and arithmetic Total Dissolved

TABLE 2
DECKER SPOILS DATA
STATISTICS SUMMARY

WELL	T (ft ^ 2/d)	LOG T	LOG TDS	TDS (mg/l)
2039	0.39	−0.40894	3.525045	3350
2043	19	1.278754	3.485721	3060
2046	23.4	1.369216	3.445915	2792
2225	23	1.361728	3.38739	2440
2226	36	1.556303	3.401401	2520
2547	288	2.459392	3.324282	2110
DS1A	366	2.563481	3.319938	2089
DS3	87	1.939519	3.307924	2032
DS4	0.22	−0.65758	3.295567	1975
DS5B	0.2	−0.69897	3.348889	2233
DS7A	496	2.695482	3.305351	2020
DS7B	255	2.40654	3.436163	2730

LOG T / ARITHMETIC TDS
Regression Output:

Constant		2564.345
Std Err of Y Est		460.5861
R Squared		0.061547
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	−89.5773	
Std Err of Coef.	110.6121	
R		0.248086
T		0.809833

ARITH T/ ARITH TDS
Regression Output:

Constant		2600.436
Std Err of Y Est		426.4853
R Squared		0.195364
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	−1.1631	
Std Err of Coef.	0.74644	
R		0.442
T		1.558199

TABLE 3
ROSEBUD SPOILS DATA
STATISTICS SUMMARY

WELL	T (ft ^ 2/d)	log T	TDS (MG/L)	log TDS
WS106	3.20832	0.506278	2930	3.466868
WS108	10.82808	1.034551	5090	3.706718
WS112	16.71	1.222976	2670	3.426511
WS113	35.02416	1.544368	3850	3.585461
WS114	272.7072	2.435697	4700	3.672098
WS115	118.4405	2.0735	3440	3.536558
WS184	34.62312	1.539366	1340	3.127105
WZ004	65.90424	1.818913	3350	3.525045
WZ002	162.8222	2.211714	1660	3.220108
S02	64.1664	1.807308	2080	3.318063
EPA3	20.052	1.302158	1044	3.0187
EPA5	2.13888	0.330186	4530	3.656098
EPA8	8.15448	0.911396	1522	3.182415
EPA10	24.0624	1.381339	2225	3.34733
EPA12	12.96696	1.112838	1097	3.040207

LOG T/ARITHMETIC TDS
Regression Output:

Constant		2802.13
Std Err of Y Est		1402.607
R Squared		0.00011
No. of Observations		15
Degrees of Freedom		13
X Coefficient(s)	−23.7346	
Std Err of Coef.	627.1117	
R		0.010496
T		0.037848

ARITH T/ ARITH TDS
Regression Output:

Constant		2512.365
Std Err of Y Est		1357.86
R Squared		0.062891
No. of Observations		15
Degrees of Freedom		13
X Coefficient(s)	4.511019	
Std Err of Coef.	4.829529	
R		0.25078
T		0.934049

TABLE 4
BIG SKY SPOILS DATA
STATISTICS SUMMARY

WELL	T	LOG T	TDS	LOG TDS
BS34	1302	3.114611	3470	3.540329
BS35	17	1.230449	3816	3.581608
BS36	0.03	−1.52288	4660	3.668386
BS19	0.94	−0.02687	4518	3.654946
BS22	0.11	−0.95861	15380	4.186956
BS37	0.07	−1.1549	4072	3.609808
BS47	147	2.167317	3644	3.561578
BS40	0.53	−0.27572	1768	3.247482
SPW1	725	2.860338	3890	3.58995
SPW2	407	2.609594	3767	3.575996

ARITH T/ ARITH TDS
Regression Output:

Constant		5386.962
Std Err of Y Est		3897.333
R Squared		0.047924
No. of Observations		10
Degrees of Freedom		8
X Coefficient(s)	−1.87893	
Std Err of Coef.	2.960912	
R		0.218916
T		0.634579

LOG T/ ARITH TDS
Regression Output:

Constant		5512.314
Std Err of Y Est		3719.764
R Squared		0.132704
No. of Observations		10
Degrees of Freedom		8
X Coefficient(s)	−763.134	
Std Err of Coef.	689.7599	
R		0.364285
T		1.106377

TABLE 5
DECKER ROSEBUD BIGSKY
SPOILS DATA

WELL	T (ft ^ 2/d)	LOG T	LOG TDS	TDS (mg/l)
2039	0.39	−0.41	3.53	3350
2043	19.00	1.28	3.49	3060
2046	23.40	1.37	3.45	2792
2225	23.00	1.36	3.39	2440
2226	36.00	1.56	3.40	2520
2547	288.00	2.46	3.32	2110
DS1A	366.00	2.56	3.32	2089
DS3	87.00	1.94	3.31	2032
DS4	0.22	−0.66	3.30	1975
DS5B	0.20	−0.70	3.35	2233
DS7A	496.00	2.70	3.31	2020
DS7B	255.00	2.41	3.44	2730
WS106	3.21	0.51	3.47	2930
WS108	10.83	1.03	3.71	5090
WS112	16.71	1.22	3.43	2670
WS113	35.02	1.54	3.59	3850
WS114	272.71	2.44	3.67	4700
WS115	118.44	2.07	3.54	3440
WS184	34.62	1.54	3.13	1340
WZ004	65.90	1.82	3.53	3350
WZ002	162.82	2.21	3.22	1660
S02	64.17	1.81	3.32	2080
EPA3	20.05	1.30	3.02	1044
EPA5	2.14	0.33	3.66	4530
EPA8	8.15	0.91	3.18	1522
EPA10	24.06	1.38	3.35	2225
EPA12	12.97	1.11	3.04	1097
BS34	1302.00	3.11	3.54	3470
BS35	17.00	1.23	3.58	3816
BS36	0.03	−1.52	3.67	4660
BS19	0.94	−0.03	3.65	4518
BS22	0.11	−0.96	4.19	15380
BS37	0.07	−1.15	3.61	4072
BS47	147.00	2.17	3.56	3644
BS40	0.53	−0.28	3.25	1768
SPW1	725.00	2.86	3.59	3890
SPW2	407.00	2.61	3.58	3767

ARITH T / ARITH TDS
Regression Output:

Constant		3275.702
Std Err of Y Est		2352.556
R Squared		0.000864
No. of Observations		37
Degrees of Freedom		35
X Coefficient(s)	−0.26497	
Std Err of Coef.	1.52303	
R		0.029395

LOG T / ARITH TDS
Regression Output:

Constant		3989.82
Std Err of Y Est		2226.539
R Squared		0.105037
No. of Observations		37
Degrees of Freedom		35
X Coefficient(s)	−614.95	
Std Err of Coef.	303.4152	
R		0.324094

ARITH T / LOG TDS
Regression Output:

Constant		3.442282
Std Err of Y Est		0.219614
R Squared		0.003898
No. of Observations		37
Degrees of Freedom		35
X Coefficient(s)	0.000053	
Std Err of Coef.	0.000142	
R		0.062433

LOG T / LOG TDS
Regression Output:

Constant		3.502084
Std Err of Y Est		0.213439
R Squared		0.059127
No. of Observations		37
Degrees of Freedom		35
X Coefficient(s)	−0.04314	
Std Err of Coef.	0.029086	
R		0.243161

Solids (TDS). As with the analyses of the individual sites, however, this is indicative of a poor correlation. In other analyses, outlying data was eliminated from consideration. This only slightly improved the correlation.

In addition to the arithmetic and logarithmic transformation of data, natural logarithmic transformations were also applied but with little success.

Discussion

All regression analyses of the transmissivity and total dissolved solids data are consistent in indicating a positive correlation. That is, the value r is always greater than zero. This implies that TDS increases with increasing transmissivity. Whereas a poor correlation suggests that the two parameters are not related, this may not be the case.

It can be shown that solute transport through a porous medium is strongly dependent on the transmitting capacity of that medium. What this analysis may suggest then, is that other mechanisms have a greater control on salt loading to the aquifer. These may include unsaturated-flow characteristics of the spoils and availability of salt for transport.

The process of strip-mining is such that material unsaturated prior to disturbance are placed below the pre-mining potentiometric surface. Distribution of the spoils material is

not uniform nor are pre-existing characteristics such as stratification and deposition patterns preserved. Some re-stratification may take place depending on the method used for removal and replacement, but this usually occurs at the base of the spoils. Upon saturation of the spoils, dissolution and precipitation of salts becomes largely a function of these factors. These analyses would imply then that while transmissivity may control salt movement, the <u>availability</u> of salts and the <u>unsaturated-flow</u> characteristics of the spoils controls the rate of loading.

REFERENCES

Huyakorn, P.S., White, H.O., and Wadsworth, T.D., 1987, A Two-Dimensional Finite Element Code for Simulation Fluid Flow and Transport of Radionuclides in Fractured and Porous Media with Water Table Conditions, Hydrogeologic, Inc., Herndon, VA.

Polubarinova-Kochina, P.YA., 1962, Theory of Groundwater Movement, 334pp., University of Princeton Press, Princeton NJ.

APPENDIX I

TRAFRAP INPUT FILE

PARTIAL OUTPUT FILE

```
  1                                                                                GROUP 1
FLOW TO A PIT OPENING SINGLE-POROSITY UNCONFINED AQUIFER JOHN METESH               GROUP 2
  1    1    0    1         1    1                                                  GROUP 3A
  1    1   10    1  100   81    0    1    1    1    2    0                         GROUP 3B
  1    5  0.0                                                                      GROUP 4
  0    0    0    1    0    0    0    0    0    0    0    1    1                    GROUP 5
     10.       00.       1.0       300.                                            GROUP 6
    0.0                                                                            GROUP 7
 0.25E+0      0.0E0      1.3E2      1.3E2      4.E-5                               GROUP 9A
    1.E0        0.0        0.0        0.0      1.E20        0.0
 10   10      1000.     1000.0    0                                                GROUP 12
   1000.      1000.     10000.     10000.        1.0        1.0        0.0        0.0GROUP 14
  1   46   56    1        250.                                                     GROUP 17
  2   56   66    1        250.                                                     ........
 19    3                                                                           GROUP 18
  1    1    0         0.                                                           GROUP 19
  3    1    0         0.                                                           ........
  5    1    0         0.
  7    1    0         0.
  9    1    0         0.
 10    1    0         0.
 21    1    0         0.
 41    1    0         0.
 61    1    0         0.
 81    1    0         0.
 20    1    0         0.
 40    1    0         0.
 60    1    0         0.
 80    1    0         0.
100    1    0         0.
 92    1    0         0.
 94    1    0         0.
 96    1    0         0.
 98    1    0         0.
 56    1    0      -80.0                                                           GROUP 20
 46    1    0      -80.0                                                           ........
 66    1    0      -80.0                                                           ........
 16    0                                                                           GROUP 27A
 56   66   46   47   45   54   55   65   67   57   76   36   37   35   77         75GROUP 27B
  1       0.0       100.    1  100         1                                       GROUP 28
  1       0.0    2  100    2    1                                                  GROUP 29
```

```
THIS OUTPUT GENERATED BY TRAFRAP-WT.F77


******************************************************************************
          NUMBER OF PROBLEMS TO BE SOLVED =    1


          PROBLEM NUMBER  1

******************************************************************************

 FLOW TO A PIT OPENING SINGLE-POROSITY UNCONFINED AQUIFER JOHN METESH

******************************************************************************

          PROBLEM CONTROL PARAMETERS
          -------------------------
          MODEL TYPE INDEX (1=FLOW, 0=TRANSPORT) . .(IMODL) =      1
          MODEL ORIENTATION (1=AREAL,0=X-SECTION). (IAREAL) =      1
          PROBLEM GEOMETRY (1=AXISYM., 0=PLANAR) . (IAXSYM) =      0
          MEDIUM TYPE (1=SINGLE, 2=DUAL POROSITY). . (MARK) =      1
          BLOCK GEOMETRY INDEX (1=SPHERE,0=PRISM). (ISHPBL) =      0
          AQUIFER TYPE (1=WATER TABLE,0=CONFINED). .(IWATP) =      1
          RECHARGE INDEX (1=RECHARGE,0=NO RECHARGE)(IVRECH) =      1


          SIMULATION CONTROL PARAMETERS
          ----------------------------
          TEMPORAL MODE INDEX(1=TRANSIENT,0=STEADY)(ITRANS) =      1
          TIME VALUE GENERATION INDEX(1=YES, 0=NO). (ITSGN) =      1
          NUMBER OF TIME STEPS . . . . . . . . . . . .(NTS) =     10
          MESH GENERATION INDEX (1=YES, 0=NO). . . (NPCODE) =      1
          NUMBER OF NODES. . . . . . . . . . . . . . . (NP) =    100
          NUMBER OF ELEMENTS . . . . . . . . . . . . . (NE) =     81
          TRIANGULAR ELEMENTS USED (1=YES, 0=NO) . (NTRIAN) =      0
          NUMBER OF DEPENDENT VARIABLES. . . . . . (NSPECI) =      1
          NUMBER OF POROUS MATRIX MATERIALS. . . . . (NMAT) =      1
          NUMBER OF FRACTURE-ZONE MATERIALS. . . . .(NAMTJ) =      1
          NUMBER OF 1-D DISCRETE FRACTURE ELEMENTS .(NLJNT) =      2
          FLUX COMPUTATION INDEX (1=YES, 0=NO) . . (IOUTLT) =      0


          TIME STEPPING AND ITERATION CONTROL PARAMETERS
          ----------------------------------------------

          TIME STEPPING INDEX-- 0=CENTRAL,1=BACKWARD(IKALL) =      1
          NO. NONLINEAR ITERATIONS PER TIME STEP . (NITMAX) =      5
          ITERATION TOLERANCE FOR HYDRAULIC HEAD . . (HTOL) =    .000E+00
```

```
INPUT/OUTPUT CONTROL PARAMETERS
-------------------------------

NUMBER OF NODES WITH INPUT COORDINATES . . .(NNP) =     0
INITIAL CONDITION NON-UNIFORMITY INDEX . . (NONU) =     0
NUMBER OF NODES FOR WHICH I.C. TO BE READ. (NPIN) =     0
DEPENDENT VARIABLE PRINTOUT CONTROL. . . .(NSTEP) =     1
VELOCITY PRINTOUT CONTROL INDEX. . . . . . (NVPR) = 10000
MESH AND I.C. DATA PRINTOUT CONTROL(3=NONE)(IPRD) =     0
MATRIX HEAD OR CONC. PRINT SUPPRESS(1=YES) (IPMD) =     0
UNIT 8 OUTPUT OF HEAD/CONC.(1=YES, 0=NO) (NOWRIT) =     0
ELEMENT VELOCITY INPUT (1=YES, 0=NO) . . (NVREAD) =     0
STEADY-STATE VELOCITY INPUT (1=YES,0=NO) (IVSTED) =     0
WRITE VELOCITIES ON UNIT 9 (1=YES, 0=NO) .(NVTAP) =     0
PRINTCHECK CONTROL (1=PRINTCHECK,0=NO) . (IPRCHK) =     1
PRINT VALUES AT OBSERVATION NODES (1=YES)(IOBSND) =     1


GENERATED TIME STEPPING DATA
----------------------------
VALUE OF FIRST TIME STEP . . . . . . . . . . .(TIN) =       .100E+02
INITIAL TIME VALUE . . . . . . . . . . . . . (TIMA) =       .000E+00
TIME STEP MULTIPLIER . . . . . . . . . . . . (TFAC) =       .100E+01
MAXIMUM ALLOWABLE VALUE OF TIME STEP . . . . (TMAX) =       .300E+03

POROUS MATRIX MATERIAL PROPERTY LIST
------------------------------------

MATERIAL NUMBER     1

SPECIFIC YIELD OF POROUS MATRIX (SY) . . . . . .  =    .250E+00
HYDRAULIC CONDUCTIVITY COMPONENT (XY). . . . . .  =    .000E+00
HYDRAULIC CONDUCTIVITY COMPONENT (XX). . . . . .  =    .130E+03
HYDRAULIC CONDUCTIVITY COMPONENT (YY). . . . . .  =    .130E+03
SPECIFIC STORAGE OF MATRIX BLOCK (SS). . . . . .  =    .400E-04

FRACTURE MATERIAL PROPERTY LIST
-------------------------------

MATERIAL NUMBER     1

FRACTURE POROSITY. . . . . . . . . . . . . . . .  =    .100E+01
FRACTURE HYDRAULIC CONDUCTIVITY COMPONENT (XY) .  =    .000E+00
FRACTURE SPECIFIC STORAGE. . . . . . . . . . . .  =    .000E+00
FRACTURE SPECIFIC YIELD. . . . . . . . . . . . .  =    .000E+00
FRACTURE HYDRAULIC CONDUCTIVITY COMPONENT (XX) .  =    .100E+21
FRACTURE HYDRAULIC CONDUCTIVITY COMPONENT (YY) .  =    .000E+00
```

MESH GENERATION PARAMETERS

```
NUMBER OF GRID LINES PARALLEL TO X-AXIS. .(NROWS) =    10
NUMBER OF GRID LINES PARALLEL TO Y-AXIS. .(NCOLS) =    10
MAXIMUM ALLOWABLE VALUE OF X-INCREMENT . .(DXMAX) =   1000.000
MAXIMUM ALLOWABLE VALUE OF Y-INCREMENT . .(DYMAX) =   1000.000
GRID LINE COORDINATE INPUT CODE. . . . . (IXYRED) =     0


X-INCREMENT OF FIRST GRID BLOCK. . . . . . . (DX) =   1000.000
Y-INCREMENT OF FIRST GRID BLOCK. . . . . . . (DY) =   1000.000
MAXIMUM VALUE OF X-COORDINATE. . . . . . . . (XO) =  10000.000
MAXIMUM VALUE OF Y-COORDINATE. . . . . . . . (YO) =  10000.000
X-INCREMENT MULTIPLIER . . . . . . . . . . (SCFX) =      1.000
Y-INCREMENT MULTIPLIER . . . . . . . . . . (SCFY) =      1.000
MINIMUM VALUE OF X-COORDINATE. . . . . . (XSTART) =       .000
MINIMUM VALUE OF Y-COORDINATE. . . . . . (YSTART) =       .000
```

LINE ELEMENT DATA

```
  ELEM #    NODE1     NODE2     MATL #   APERTURE       ELEM #     NODE1     NODE2
MATL #  APERTURE
      1       46        56         1      .2500E+03        2         56        66
   1      .2500E+03
```

BOUNDARY CONDITION SPECIFICATION DATA

```
TOTAL NUMBER OF DIRICHLET B.C. =    19

TOTAL NUMBER OF FLUX B.C.      =     3
```

DIRICHLET BOUNDARY CONDITION DATA

NODE#	DEP. VARIABLE#	B.C. CODE	PRESCRIBED VALUE
1	1	0	.0000E+00
3	1	0	.0000E+00
5	1	0	.0000E+00
7	1	0	.0000E+00
9	1	0	.0000E+00
10	1	0	.0000E+00
21	1	0	.0000E+00
41	1	0	.0000E+00
61	1	0	.0000E+00
81	1	0	.0000E+00
20	1	0	.0000E+00
40	1	0	.0000E+00
60	1	0	.0000E+00
80	1	0	.0000E+00
100	1	0	.0000E+00
92	1	0	.0000E+00
94	1	0	.0000E+00
96	1	0	.0000E+00
98	1	0	.0000E+00

FLUX BOUNDARY CONDITION DATA

NODE#	DEP. VARIABLE#	B.C. CODE	FLUID FLUX
56	1	0	-.8000E+02
46	1	0	-.8000E+02
66	1	0	-.8000E+02

OBSERVATION NODE DATA

NUMBER OF OBSERVATION NODES . . . . (NNDOBS) = 16
NON-DIMENSIONAL CONVERSION INDEX. .(1 = CONVERT) = 0

LIST OF OBSERVATION NODE NUMBERS

56 66 46 47 45 54 55 65 67 57 76 36 37
35 77 75

LIST OF NODE NUMBERS AND X AND Y COORDINATES

NODE	X-COORD.	Y-COORD.	NODE	X-COORD.	Y-COORD.	NODE	X-COORD.	Y-COORD.
1	.000	.000	2	.000	1000.000	3	.000	2000.000
4	.000	3000.000	5	.000	4000.000	6	.000	5000.000
7	.000	6000.000	8	.000	7000.000	9	.000	8500.000
10	.000	10000.000	11	1000.000	.000	12	1000.000	1000.000
13	1000.000	2000.000	14	1000.000	3000.000	15	1000.000	4000.000
16	1000.000	5000.000	17	1000.000	6000.000	18	1000.000	7000.000
19	1000.000	8500.000	20	1000.000	10000.000	21	2000.000	.000
22	2000.000	1000.000	23	2000.000	2000.000	24	2000.000	3000.000
25	2000.000	4000.000	26	2000.000	5000.000	27	2000.000	6000.000
28	2000.000	7000.000	29	2000.000	8500.000	30	2000.000	10000.000
31	3000.000	.000	32	3000.000	1000.000	33	3000.000	2000.000
34	3000.000	3000.000	35	3000.000	4000.000	36	3000.000	5000.000
37	3000.000	6000.000	38	3000.000	7000.000	39	3000.000	8500.000
40	3000.000	10000.000	41	4000.000	.000	42	4000.000	1000.000
43	4000.000	2000.000	44	4000.000	3000.000	45	4000.000	4000.000
46	4000.000	5000.000	47	4000.000	6000.000	48	4000.000	7000.000
49	4000.000	8500.000	50	4000.000	10000.000	51	5000.000	.000
52	5000.000	1000.000	53	5000.000	2000.000	54	5000.000	3000.000
55	5000.000	4000.000	56	5000.000	5000.000	57	5000.000	6000.000
58	5000.000	7000.000	59	5000.000	8500.000	60	5000.000	10000.000
61	6000.000	.000	62	6000.000	1000.000	63	6000.000	2000.000
64	6000.000	3000.000	65	6000.000	4000.000	66	6000.000	5000.000
67	6000.000	6000.000	68	6000.000	7000.000	69	6000.000	8500.000
70	6000.000	10000.000	71	7000.000	.000	72	7000.000	1000.000
73	7000.000	2000.000	74	7000.000	3000.000	75	7000.000	4000.000
76	7000.000	5000.000	77	7000.000	6000.000	78	7000.000	7000.000
79	7000.000	8500.000	80	7000.000	10000.000	81	8500.000	.000
82	8500.000	1000.000	83	8500.000	2000.000	84	8500.000	3000.000
85	8500.000	4000.000	86	8500.000	5000.000	87	8500.000	6000.000
88	8500.000	7000.000	89	8500.000	8500.000	90	8500.000	10000.000
91	10000.000	.000	92	10000.000	1000.000	93	10000.000	2000.000
94	10000.000	3000.000	95	10000.000	4000.000	96	10000.000	5000.000
97	10000.000	6000.000	98	10000.000	7000.000	99	10000.000	8500.000
100	10000.000	10000.000						

LIST OF NODE NUMBERS AND CORRESPONDING HEAD VALUES

1	.0000E+00	2	.9373E-03	3	.0000E+00	4	.1759E-02	5	.0000E+00
6	.2223E-02	7	.0000E+00	8	.2041E-02	9	.0000E+00	10	.0000E+00
11	.9209E-03	12	.1019E-02	13	.1809E-02	14	.2279E-02	15	.2948E-02
16	.2943E-02	17	.3002E-02	18	.2403E-02	19	.1381E-02	20	.0000E+00
21	.0000E+00	22	.1727E-02	23	.2762E-02	24	.3988E-02	25	.4968E-02
26	.5422E-02	27	.4983E-02	28	.3998E-02	29	.2038E-02	30	.9876E-03
31	.1571E-02	32	.2056E-02	33	.3674E-02	34	.5543E-02	35	.7925E-02
36	.8696E-02	37	.7912E-02	38	.5483E-02	39	.2883E-02	40	.0000E+00
41	.0000E+00	42	.2501E-02	43	.4215E-02	44	.6602E-02	45	.1021E-01
46	.1797E-01	47	.1018E-01	48	.6565E-02	49	.3031E-02	50	.1439E-02
51	.1814E-02	52	.2381E-02	53	.4295E-02	54	.6671E-02	55	.1028E-01
56	.1797E-01	57	.1026E-01	58	.6588E-02	59	.3341E-02	60	.0000E+00
61	.0000E+00	62	.2372E-02	63	.3853E-02	64	.5764E-02	65	.8146E-02
66	.8929E-02	67	.8135E-02	68	.5758E-02	69	.2822E-02	70	.1370E-02
71	.1632E-02	72	.1889E-02	73	.3114E-02	74	.4339E-02	75	.5410E-02
76	.5805E-02	77	.5420E-02	78	.4349E-02	79	.2573E-02	80	.0000E+00
81	.0000E+00	82	.1181E-02	83	.1661E-02	84	.2380E-02	85	.2574E-02
86	.2945E-02	87	.2596E-02	88	.2461E-02	89	.1508E-02	90	.1353E-02
91	.5907E-03	92	.0000E+00	93	.8263E-03	94	.0000E+00	95	.1232E-02
96	.0000E+00	97	.1252E-02	98	.0000E+00	99	.1331E-02	100	.0000E+00

^Z

TRAFRAP OUTPUT

X-COORD	Y-COORD	DRAWDOWN
0.000	0.000	0.0000E+00
0.000	1000.000	9.3730E-04
0.000	2000.000	0.0000E+00
0.000	3000.000	1.7590E-03
0.000	4000.000	0.0000E+00
0.000	5000.000	2.2230E-03
0.000	6000.000	0.0000E+00
0.000	7000.000	2.0410E-03
0.000	8500.000	0.0000E+00
0.000	10000.000	0.0000E+00
1000.000	0.000	9.2090E-04
1000.000	1000.000	1.0190E-03
1000.000	2000.000	1.8090E-03
1000.000	3000.000	2.2790E-03
1000.000	4000.000	2.9480E-03
1000.000	5000.000	2.9430E-03
1000.000	6000.000	3.0020E-03
1000.000	7000.000	2.4030E-03
1000.000	8500.000	1.3810E-03
1000.000	10000.000	0.0000E+00
2000.000	0.000	0.0000E+00
2000.000	1000.000	1.7270E-03
2000.000	2000.000	2.7620E-03
2000.000	3000.000	3.9880E-03
2000.000	4000.000	4.9680E-03
2000.000	5000.000	5.4220E-03
2000.000	6000.000	4.9830E-03
2000.000	7000.000	3.9980E-03
2000.000	8500.000	2.0380E-03
2000.000	10000.000	9.8760E-04
3000.000	0.000	1.5710E-03
3000.000	1000.000	2.0560E-03
3000.000	2000.000	3.6740E-03
3000.000	3000.000	5.5430E-03
3000.000	4000.000	7.9250E-03
3000.000	5000.000	8.6960E-03
3000.000	6000.000	7.9120E-03
3000.000	7000.000	5.4830E-03
3000.000	8500.000	2.8830E-03
3000.000	10000.000	0.0000E+00
4000.000	0.000	0.0000E+00
4000.000	1000.000	2.5010E-03
4000.000	2000.000	4.2150E-03
4000.000	3000.000	6.6020E-03
4000.000	4000.000	1.2100E-02
4000.000	5000.000	1.7970E-02
4000.000	6000.000	1.0180E-02
4000.000	7000.000	6.5650E-03
4000.000	8500.000	3.0310E-03
4000.000	10000.000	1.4390E-03
5000.000	0.000	1.8140E-03
5000.000	1000.000	2.3810E-03
5000.000	2000.000	4.2950E-03
5000.000	3000.000	6.6710E-03
5000.000	4000.000	1.0280E-02
5000.000	5000.000	1.7970E-02
5000.000	6000.000	1.0260E-02
5000.000	7000.000	6.5880E-03
5000.000	8500.000	3.3410E-03
5000.000	10000.000	0.0000E+00
6000.000	0.000	0.0000E+00
6000.000	1000.000	2.3720E-03
6000.000	2000.000	3.8530E-03
6000.000	3000.000	5.7640E-03
6000.000	4000.000	8.1460E-03
6000.000	5000.000	8.9290E-03
6000.000	6000.000	8.1350E-03
6000.000	7000.000	5.7580E-03

TRAFRAP OUTPUT (continued)

X-COORD	Y-COORD	DRAWDOWN
6000.000	8500.000	2.8220E-03
6000.000	10000.000	1.3700E-03
7000.000	0.000	1.6320E-03
7000.000	1000.000	1.8890E-03
7000.000	2000.000	3.1140E-03
7000.000	3000.000	4.3390E-03
7000.000	4000.000	5.4100E-03
7000.000	5000.000	5.8050E-03
7000.000	6000.000	5.4200E-03
7000.000	7000.000	4.3490E-03
7000.000	8500.000	2.5730E-03
7000.000	10000.000	0.0000E+00
8500.000	0.000	0.0000E+00
8500.000	1000.000	1.1810E-03
8500.000	2000.000	1.6610E-03
8500.000	3000.000	2.3800E-03
8500.000	4000.000	2.5740E-03
8500.000	5000.000	2.9450E-03
8500.000	6000.000	2.5960E-03
8500.000	7000.000	2.4610E-03
8500.000	8500.000	1.5080E-03
8500.000	10000.000	1.3530E-03
10000.000	0.000	5.9070E-04
10000.000	1000.000	0.0000E+00
10000.000	2000.000	8.2630E-04
10000.000	3000.000	0.0000E+00
10000.000	4000.000	1.2320E-03
10000.000	5000.000	0.0000E+00
10000.000	6000.000	1.2520E-03
10000.000	7000.000	0.0000E+00
10000.000	8500.000	1.3310E-03
10000.000	10000.000	0.0000E+00

FLOW TO OPEN PIT
ELLIPTICAL SOLUTION

INPUT:	Q(ft^3/d)	80					
	K(ft/d)	0.5					
	2L(feet)	1000					
				X1	Y1	X2	Y2
	PIT =>			4000	5000	5000	5000

X COORD	Y COORD	DRAWDOWN	X COORD	Y COORD	DRAWDOWN
0	0	0.001893	6000	6000	0.007159
0	1000	0.002116	6000	6100	0.006922
0	2000	0.002358	6000	6200	0.006688
0	3000	0.002592	6000	6300	0.006461
0	4000	0.002772	6000	6400	0.006241
0	5000	0.002841	6000	6500	0.006028
0	6000	0.002772	6000	6600	0.005824
0	7000	0.002592	6000	6700	0.005629
0	8000	0.002358	6000	6800	0.005443
0	9000	0.002116	6000	6900	0.005265
0	10000	0.001893	6000	7000	0.005095
0	11000	0.001698	6000	7100	0.004934
0	12000	0.00153	6000	7200	0.00478
0	13000	0.001387	6000	7300	0.004634
0	14000	0.001265	6000	7400	0.004495
0	15000	0.001161	6000	7500	0.004363
0	16000	0.001071	6000	7600	0.004237
0	17000	0.000993	6000	7700	0.004117
0	18000	0.000925	6000	7800	0.004003
0	19000	0.000866	6000	7900	0.003894
0	20000	0.000813	6000	8000	0.00379
1000	0	0.002086	6000	8100	0.003692
1000	1000	0.002397	6000	8200	0.003597
1000	2000	0.002766	6000	8300	0.003507
1000	3000	0.003169	6000	8400	0.003421
1000	4000	0.003518	6000	8500	0.003339
1000	5000	0.003663	6000	8600	0.00326
1000	6000	0.003518	6000	8700	0.003184
1000	7000	0.003169	6000	8800	0.003112
1000	8000	0.002766	6000	8900	0.003043
1000	9000	0.002397	6000	9000	0.002976
1000	10000	0.002086	6000	9100	0.002912
1000	11000	0.001833	6000	9200	0.002851
1000	12000	0.001626	6000	9300	0.002792
1000	13000	0.001458	6000	9400	0.002735
1000	14000	0.001318	6000	9500	0.002681
1000	15000	0.001201	6000	9600	0.002628
1000	16000	0.001103	6000	9700	0.002578
1000	17000	0.001018	6000	9800	0.002529
1000	18000	0.000946	6000	9900	0.002482
1000	19000	0.000882	6000	10000	0.002436
1000	20000	0.000827	7000	6000	0.004772
2000	0	0.002276	7000	6100	0.004701
2000	1000	0.002698	7000	6200	0.004627
2000	2000	0.003262	7000	6300	0.004551
2000	3000	0.00399	7000	6400	0.004473
2000	4000	0.004772	7000	6500	0.004393
2000	5000	0.005163	7000	6600	0.004312
2000	6000	0.004772	7000	6700	0.004232
2000	7000	0.00399	7000	6800	0.004151
2000	8000	0.003262	7000	6900	0.00407
2000	9000	0.002698	7000	7000	0.00399
2000	10000	0.002276	7000	7100	0.003911
2000	11000	0.001958	7000	7200	0.003833
2000	12000	0.001712	7000	7300	0.003756
2000	13000	0.001518	7000	7400	0.003681
2000	14000	0.001363	7000	7500	0.003607
2000	15000	0.001235	7000	7600	0.003535

X COORD	Y COORD	DRAWDOWN
2000	16000	0.001128
2000	17000	0.001038
2000	18000	0.000962
2000	19000	0.000895
2000	20000	0.000837
3000	0	0.002436
3000	1000	0.002976
3000	2000	0.00379
3000	3000	0.005095
3000	4000	0.007159
3000	5000	0.008825
3000	6000	0.007159
3000	7000	0.005095
3000	8000	0.00379
3000	9000	0.002976
3000	10000	0.002436
3000	11000	0.002057
3000	12000	0.001777
3000	13000	0.001563
3000	14000	0.001395
3000	15000	0.001259
3000	16000	0.001147
3000	17000	0.001053
3000	18000	0.000973
3000	19000	0.000904
3000	20000	0.000844
4000	0	0.00253
4000	1000	0.003151
4000	2000	0.004169
4000	3000	0.006127
4000	4000	0.011222
4000	5000	0.011222
4000	6000	0.011222
4000	7000	0.006127
4000	8000	0.004169
4000	9000	0.003151
4000	10000	0.00253
4000	11000	0.002112
4000	12000	0.001813
4000	13000	0.001587
4000	14000	0.001412
4000	15000	0.001271
4000	16000	0.001156
4000	17000	0.00106
4000	18000	0.000978
4000	19000	0.000909
4000	20000	0.000848
5000	0	0.00253
5000	1000	0.003151
5000	2000	0.004169
5000	3000	0.006127
5000	4000	0.011222
5000	5000	0.011222
5000	6000	0.011222
5000	7000	0.006127
5000	8000	0.004169
5000	9000	0.003151
5000	10000	0.00253
5000	11000	0.002112
5000	12000	0.001813
5000	13000	0.001587
5000	14000	0.001412
5000	15000	0.001271
5000	16000	0.001156
5000	17000	0.00106
5000	18000	0.000978
5000	19000	0.000909
5000	20000	0.000848
6000	0	0.002436
6000	1000	0.002976

X COORD	Y COORD	DRAWDOWN
7000	7700	0.003464
7000	7800	0.003395
7000	7900	0.003328
7000	8000	0.003262
7000	8100	0.003199
7000	8200	0.003136
7000	8300	0.003076
7000	8400	0.003017
7000	8500	0.00296
7000	8600	0.002905
7000	8700	0.002851
7000	8800	0.002799
7000	8900	0.002748
7000	9000	0.002698
7000	9100	0.002651
7000	9200	0.002604
7000	9300	0.002559
7000	9400	0.002515
7000	9500	0.002472
7000	9600	0.002431
7000	9700	0.002391
7000	9800	0.002351
7000	9900	0.002313
7000	10000	0.002276
8000	6000	0.003518
8000	6100	0.003489
8000	6200	0.003459
8000	6300	0.003427
8000	6400	0.003393
8000	6500	0.003359
8000	6600	0.003322
8000	6700	0.003285
8000	6800	0.003247
8000	6900	0.003208
8000	7000	0.003169
8000	7100	0.003129
8000	7200	0.003089
8000	7300	0.003048
8000	7400	0.003007
8000	7500	0.002967
8000	7600	0.002926
8000	7700	0.002886
8000	7800	0.002846
8000	7900	0.002806
8000	8000	0.002766
8000	8100	0.002727
8000	8200	0.002688
8000	8300	0.00265
8000	8400	0.002612
8000	8500	0.002575
8000	8600	0.002538
8000	8700	0.002502
8000	8800	0.002466
8000	8900	0.002431
8000	9000	0.002397
8000	9100	0.002363
8000	9200	0.00233
8000	9300	0.002297
8000	9400	0.002265
8000	9500	0.002234
8000	9600	0.002203
8000	9700	0.002173
8000	9800	0.002143
8000	9900	0.002114
8000	10000	0.002086
9000	6000	0.002772
9000	6100	0.002758
9000	6200	0.002743
9000	6300	0.002727
9000	6400	0.002711

X COORD	Y COORD	DRAWDOWN
6000	2000	0.00379
6000	3000	0.005095
6000	4000	0.007159
6000	5000	0.008825
6000	6000	0.007159
6000	7000	0.005095
6000	8000	0.00379
6000	9000	0.002976
6000	10000	0.002436
6000	11000	0.002057
6000	12000	0.001777
6000	13000	0.001563
6000	14000	0.001395
6000	15000	0.001259
6000	16000	0.001147
6000	17000	0.001053
6000	18000	0.000973
6000	19000	0.000904
6000	20000	0.000844
7000	0	0.002276
7000	1000	0.002698
7000	2000	0.003262
7000	3000	0.00399
7000	4000	0.004772
7000	5000	0.005163
7000	6000	0.004772
7000	7000	0.00399
7000	8000	0.003262
7000	9000	0.002698
7000	10000	0.002276
7000	11000	0.001958
7000	12000	0.001712
7000	13000	0.001518
7000	14000	0.001363
7000	15000	0.001235
7000	16000	0.001128
7000	17000	0.001038
7000	18000	0.000962
7000	19000	0.000895
7000	20000	0.000837
8000	0	0.002086
8000	1000	0.002397
8000	2000	0.002766
8000	3000	0.003169
8000	4000	0.003518
8000	5000	0.003663
8000	6000	0.003518
8000	7000	0.003169
8000	8000	0.002766
8000	9000	0.002397
8000	10000	0.002086
8000	11000	0.001833
8000	12000	0.001626
8000	13000	0.001458
8000	14000	0.001318
8000	15000	0.001201
8000	16000	0.001103
8000	17000	0.001018
8000	18000	0.000946
8000	19000	0.000882
8000	20000	0.000827
9000	0	0.001893
9000	1000	0.002116
9000	2000	0.002358
9000	3000	0.002592
9000	4000	0.002772
9000	5000	0.002841
9000	6000	0.002772
9000	7000	0.002592
9000	8000	0.002358

X COORO	Y COORD	DRAWDOWN
9000	6500	0.002693
9000	6600	0.002674
9000	6700	0.002655
9000	6800	0.002634
9000	6900	0.002614
9000	7000	0.002592
9000	7100	0.00257
9000	7200	0.002548
9000	7300	0.002525
9000	7400	0.002502
9000	7500	0.002478
9000	7600	0.002455
9000	7700	0.002431
9000	7800	0.002406
9000	7900	0.002382
9000	8000	0.002358
9000	8100	0.002333
9000	8200	0.002309
9000	8300	0.002285
9000	8400	0.00226
9000	8500	0.002236
9000	8600	0.002212
9000	8700	0.002188
9000	8800	0.002164
9000	8900	0.00214
9000	9000	0.002116
9000	9100	0.002093
9000	9200	0.00207
9000	9300	0.002047
9000	9400	0.002024
9000	9500	0.002002
9000	9600	0.00198
9000	9700	0.001958
9000	9800	0.001936
9000	9900	0.001915
9000	10000	0.001893
10000	6000	0.002283
10000	6100	0.002276
10000	6200	0.002267
10000	6300	0.002258
10000	6400	0.002249
10000	6500	0.002239
10000	6600	0.002228
10000	6700	0.002217
10000	6800	0.002205
10000	6900	0.002193
10000	7000	0.00218
10000	7100	0.002167
10000	7200	0.002153
10000	7300	0.00214
10000	7400	0.002126
10000	7500	0.002111
10000	7600	0.002096
10000	7700	0.002081
10000	7800	0.002066
10000	7900	0.002051
10000	8000	0.002035
10000	8100	0.002019
10000	8200	0.002004
10000	8300	0.001988
10000	8400	0.001971
10000	8500	0.001955
10000	8600	0.001939
10000	8700	0.001923
10000	8800	0.001906
10000	8900	0.00189
10000	9000	0.001874
10000	9100	0.001858
10000	9200	0.001841
10000	9300	0.001825

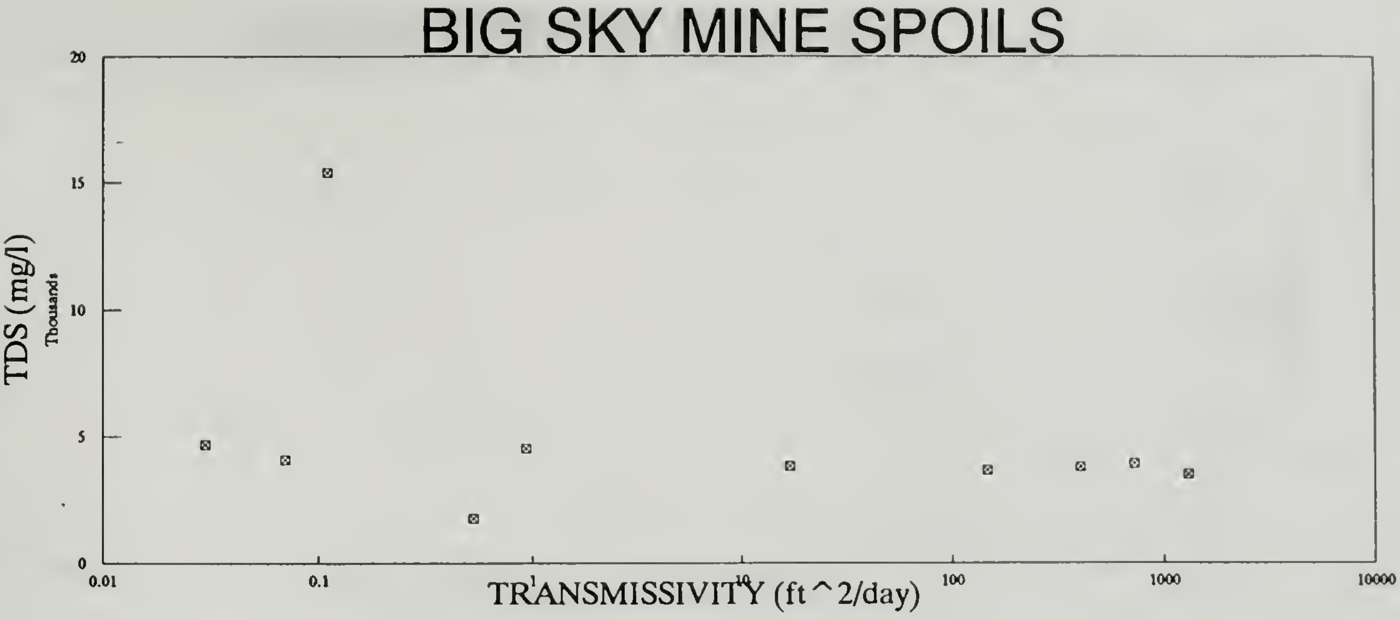
X COORD	Y COORD	DRAWDOWN
9000	9000	0.002116
9000	10000	0.001893
9000	11000	0.001698
9000	12000	0.00153
9000	13000	0.001387
9000	14000	0.001265
9000	15000	0.001161
9000	16000	0.001071
9000	17000	0.000993
9000	18000	0.000925
9000	19000	0.000866
9000	20000	0.000813
10000	0	0.001714
10000	1000	0.001874
10000	2000	0.002035
10000	3000	0.00218
10000	4000	0.002283
10000	5000	0.002321
10000	6000	0.002283
10000	7000	0.00218
10000	8000	0.002035
10000	9000	0.001874
10000	10000	0.001714
10000	11000	0.001565
10000	12000	0.00143
10000	13000	0.001311
10000	14000	0.001207
10000	15000	0.001116
10000	16000	0.001035
10000	17000	0.000964
10000	18000	0.000902
10000	19000	0.000846
10000	20000	0.000797
11000	0	0.001553
11000	1000	0.00167
11000	2000	0.001781
11000	3000	0.001875
11000	4000	0.00194
11000	5000	0.001963
11000	6000	0.00194
11000	7000	0.001875
11000	8000	0.001781
11000	9000	0.00167
11000	10000	0.001553
11000	11000	0.00144
11000	12000	0.001333
11000	13000	0.001235
11000	14000	0.001147
11000	15000	0.001068
11000	16000	0.000996
11000	17000	0.000933
11000	18000	0.000876
11000	19000	0.000825
11000	20000	0.000779
12000	0	0.001413
12000	1000	0.001499
12000	2000	0.001578
12000	3000	0.001642
12000	4000	0.001685
12000	5000	0.0017
12000	6000	0.001685
12000	7000	0.001642
12000	8000	0.001578
12000	9000	0.001499
12000	10000	0.001413
12000	11000	0.001326
12000	12000	0.001241
12000	13000	0.001161
12000	14000	0.001087
12000	15000	0.001019

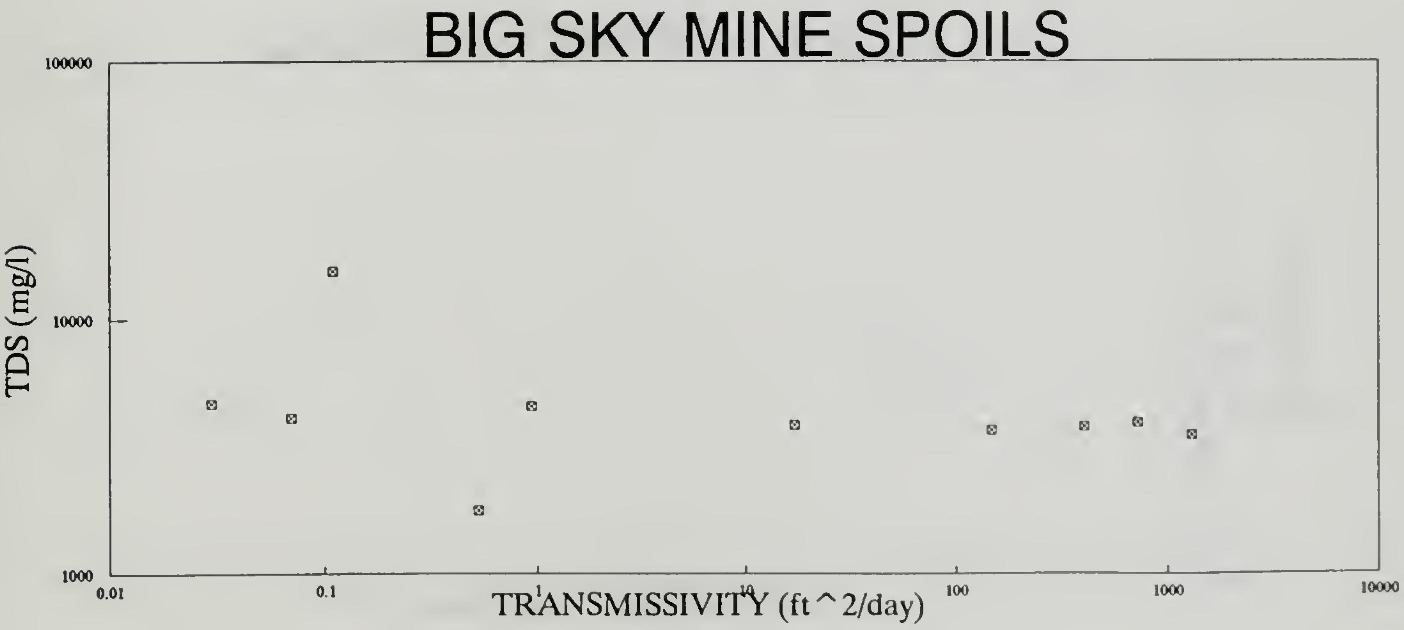
X COORD	Y COORD	DRAWDOWN
10000	9400	0.001809
10000	9500	0.001793
10000	9600	0.001777
10000	9700	0.001761
10000	9800	0.001745
10000	9900	0.001729
10000	10000	0.001714

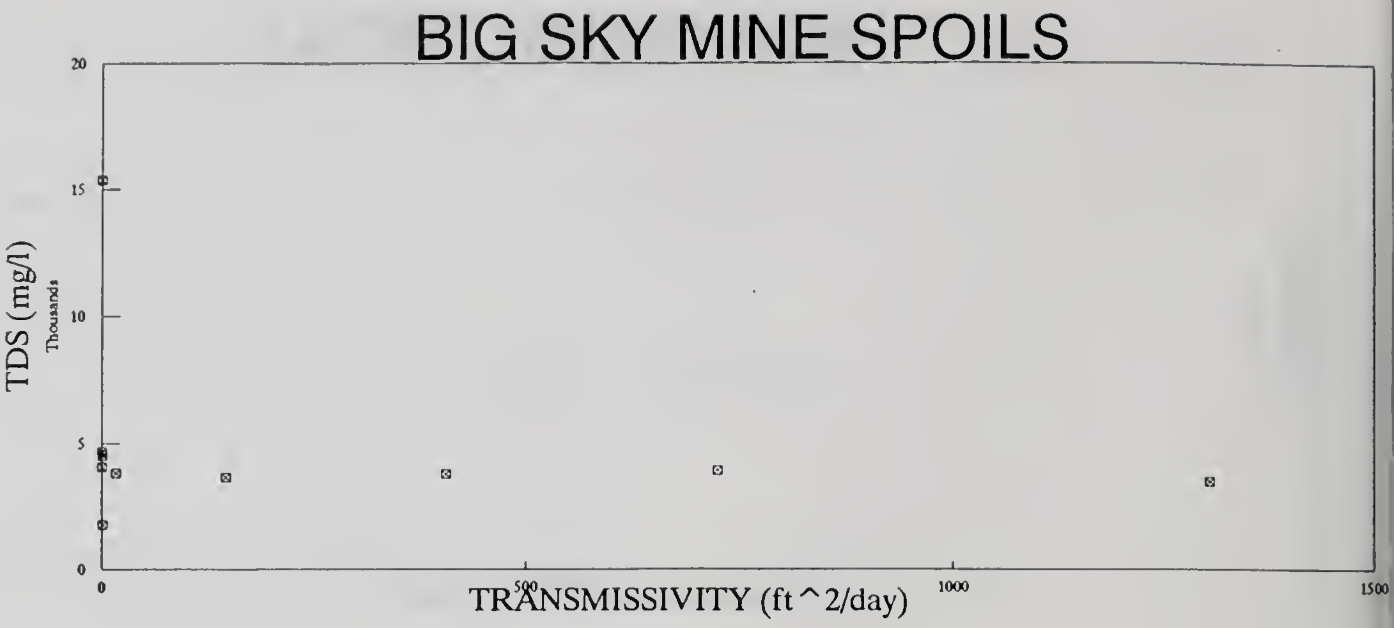
X COORD	Y COORD	DRAWDOWN
12000	16000	0.000956
12000	17000	0.0009
12000	18000	0.000848
12000	19000	0.000802
12000	20000	0.000759

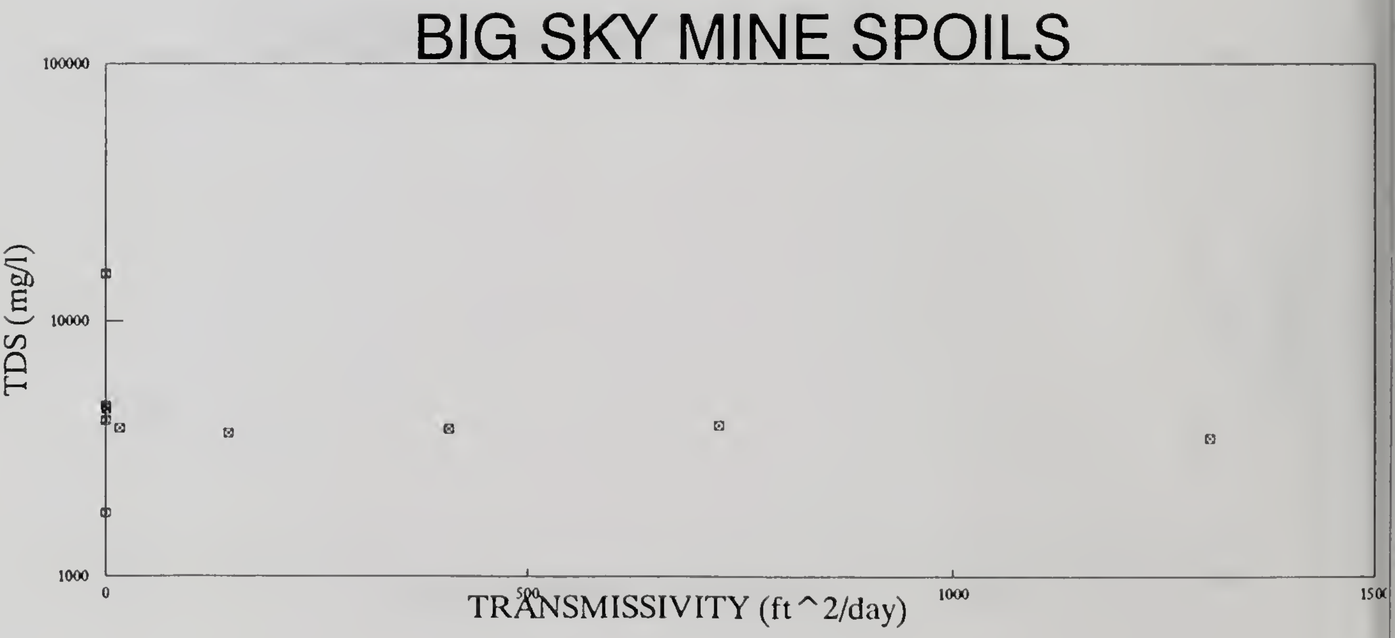
APPENDIX II

PLOTS OF DATA USED FOR REGRESSION ANALYSES

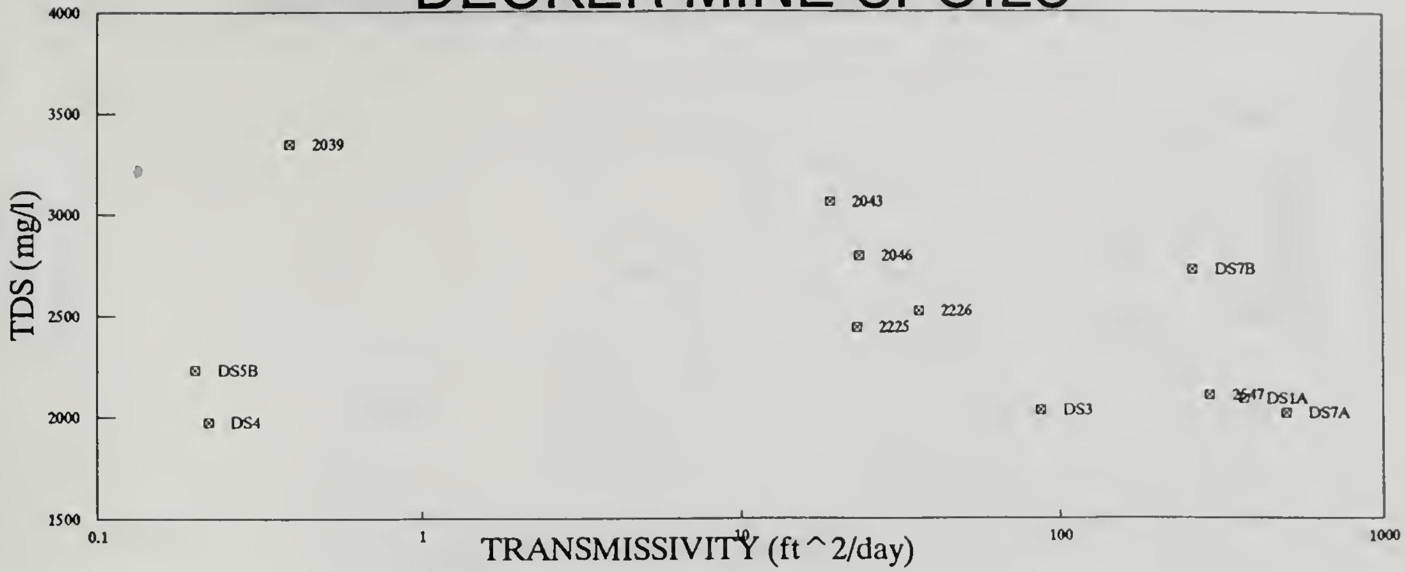

BIG SKY MINE SPOILS
TDS (mg/l)
Thousands
20
15
10
5
0
0.01
0.1
1
10
100
1000
10000
TRANSMISSIVITY (ft^2/day)


BIG SKY MINE SPOILS
TDS (mg/l)
100000
10000
1000
0.01
0.1
1
10
100
1000
10000
TRANSMISSIVITY (ft^2/day)

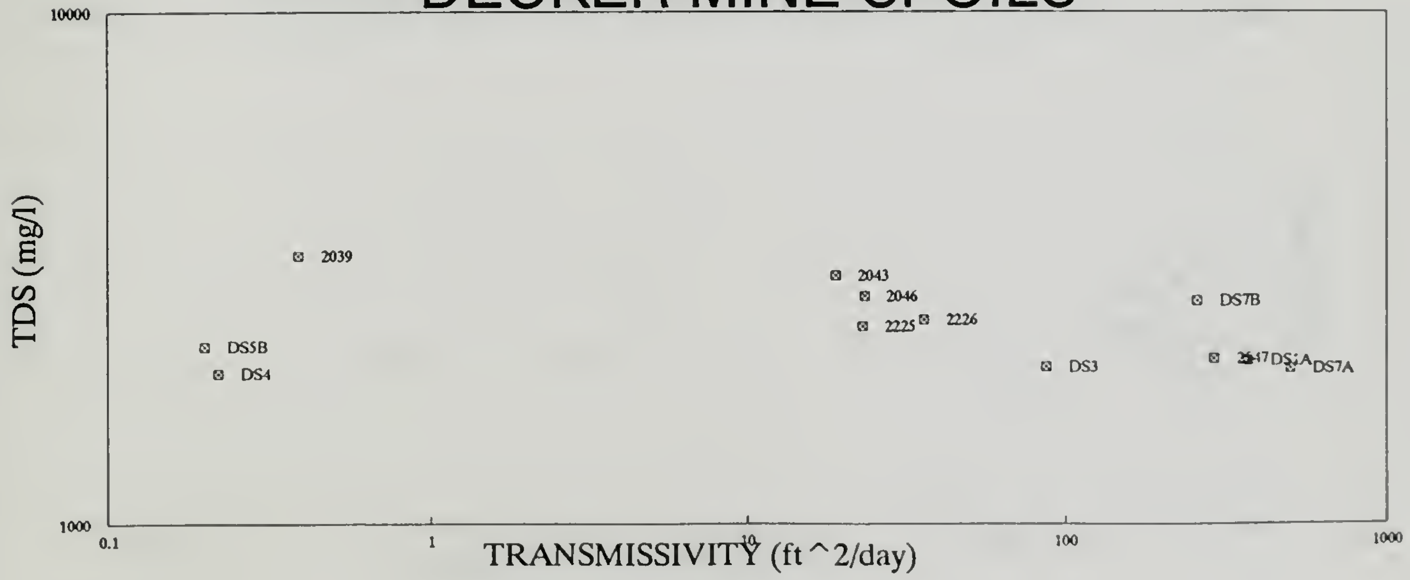

BIG SKY MINE SPOILS
TDS (mg/l)
Thousands
20
15
10
5
0
0
500
1000
1500
TRANSMISSIVITY (ft^2/day)

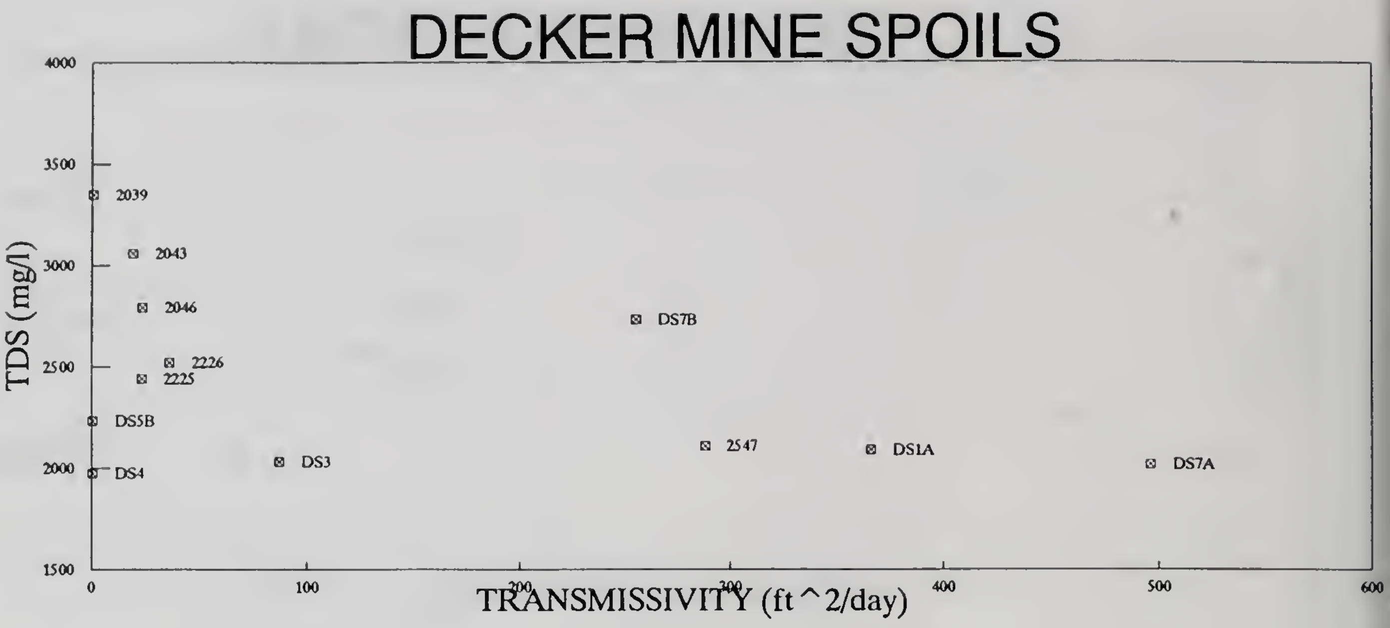

BIG SKY MINE SPOILS
TDS (mg/l)
100000
10000
1000
0
500
1000
TRANSMISSIVITY (ft^2/day)

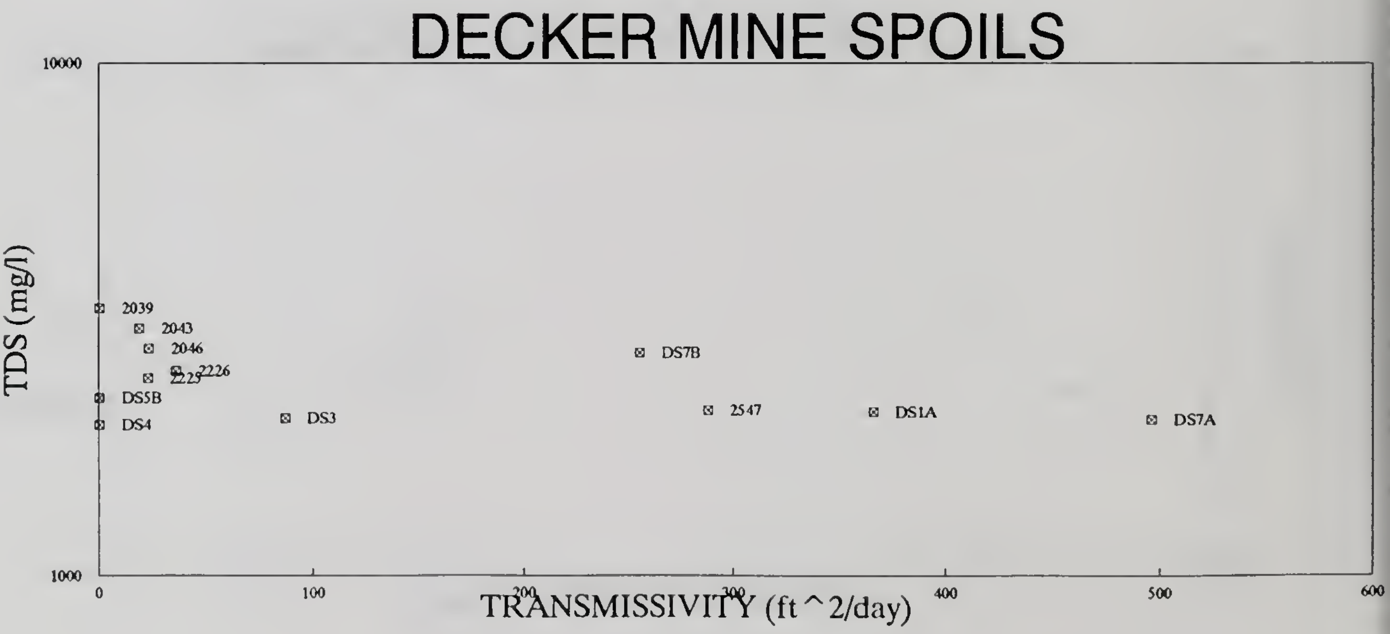
DECKER MINE SPOILS

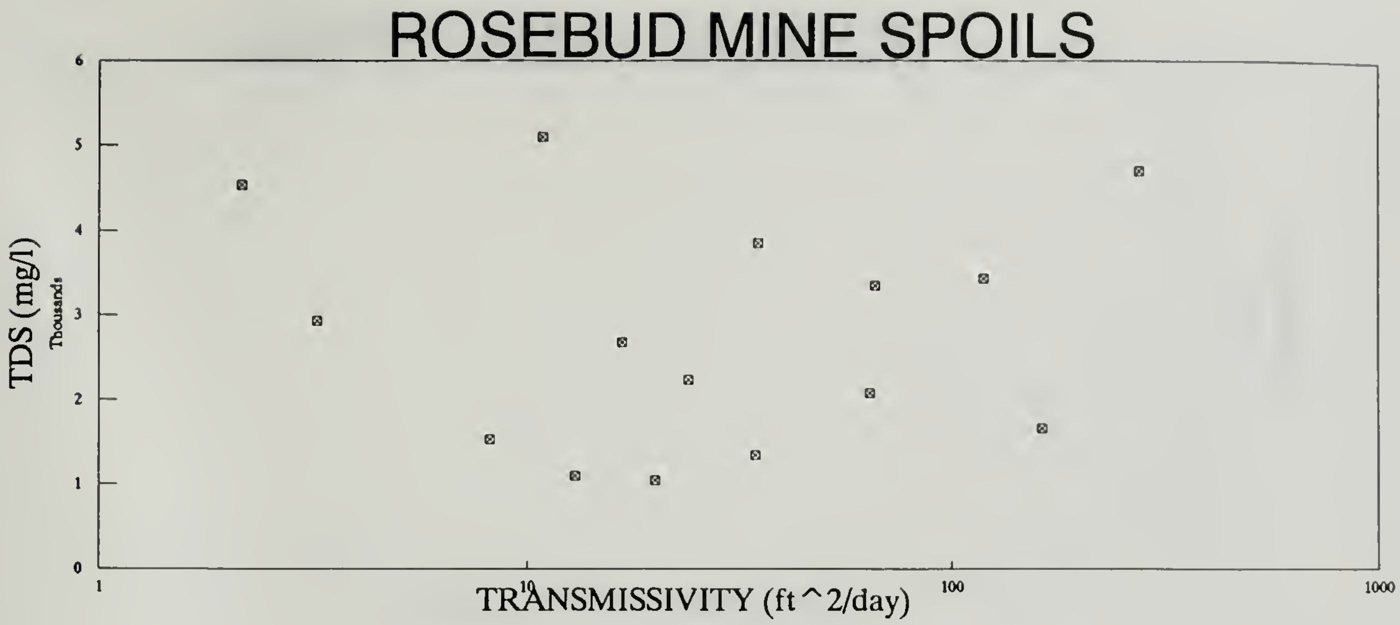


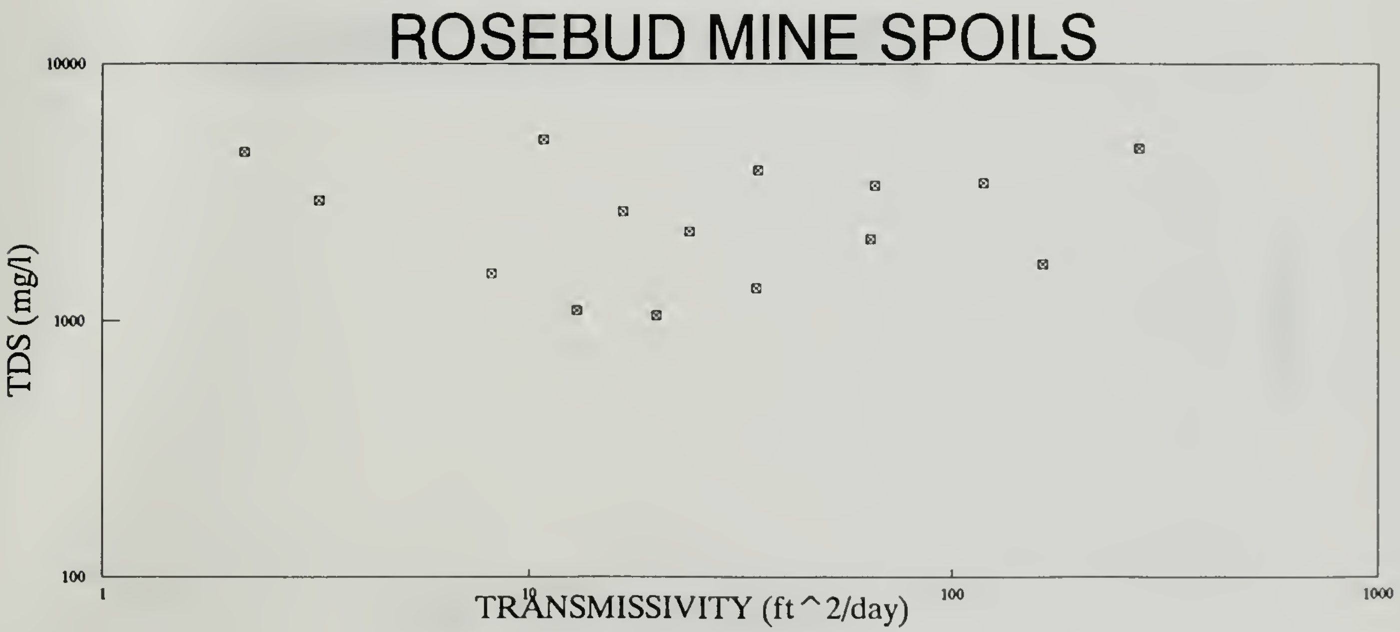
DECKER MINE SPOILS

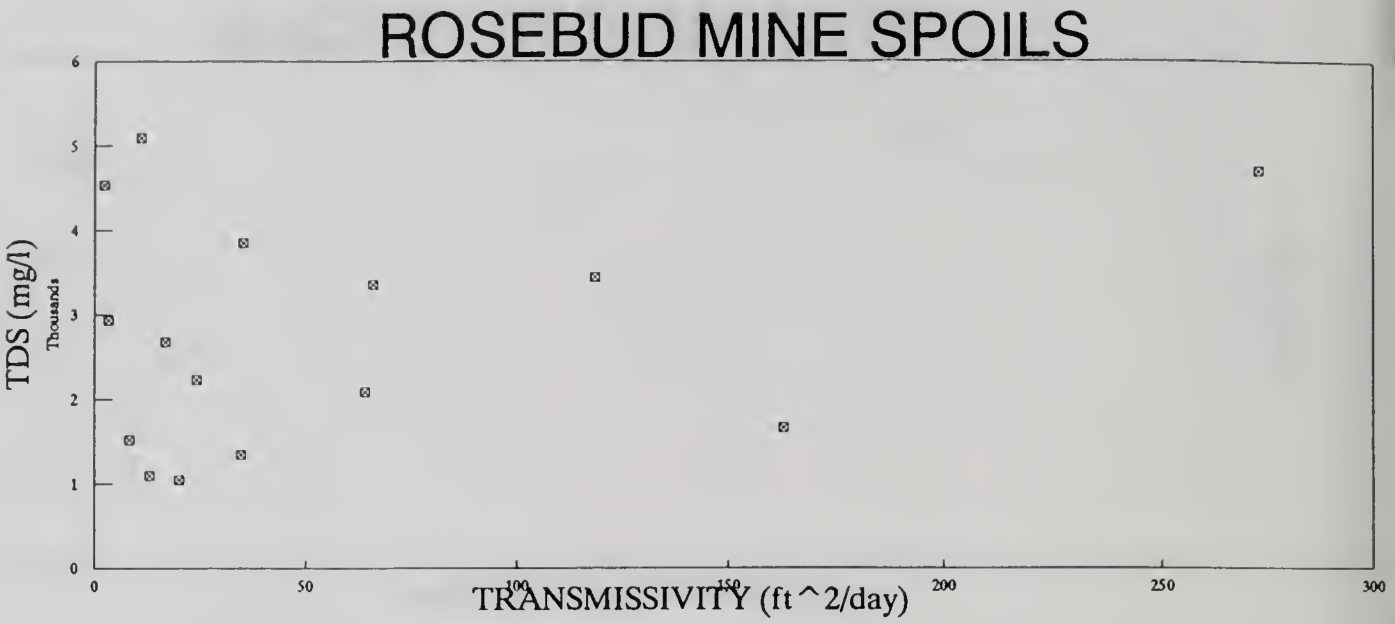


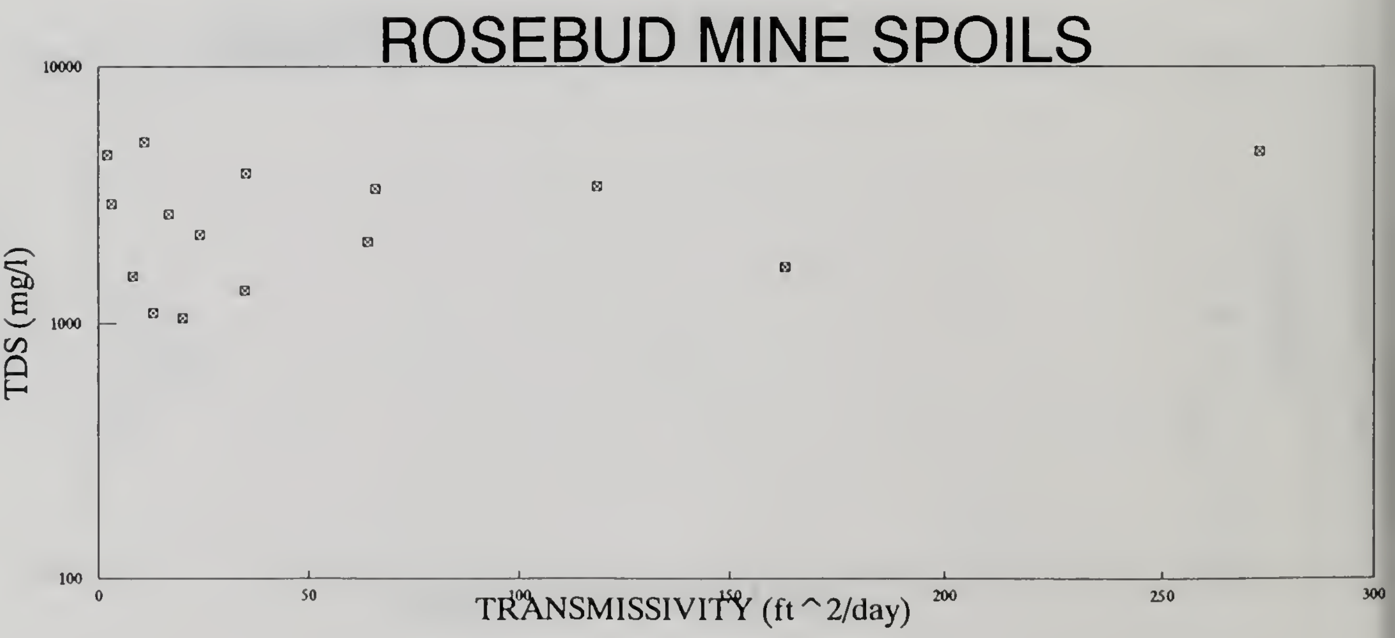

DECKER MINE SPOILS
TDS (mg/l)
TRANSMISSIVITY (ft^2/day)
4000
3500
3000
2500
2000
1500
0
100
200
300
400
500
600
2039
2043
2046
2226
2225
DS5B
DS4
DS3
DS7B
2547
DS1A
DS7A


DECKER MINE SPOILS
TDS (mg/l)
TRANSMISSIVITY (ft^2/day)
10000
1000
0
100
200
300
400
500
600
2039
2043
2046
2226
2225
DS5B
DS4
DS3
DS7B
2547
DS1A
DS7A


ROSEBUD MINE SPOILS
TDS (mg/l)
Thousands
0
1
2
3
4
5
6
1
10
100
1000
TRANSMISSIVITY (ft^2/day)


ROSEBUD MINE SPOILS
TDS (mg/l)
100
1000
10000
1
10
100
1000
TRANSMISSIVITY (ft^2/day)


ROSEBUD MINE SPOILS
TDS (mg/l)
Thousands
0
1
2
3
4
5
6
0
50
100
150
200
250
300
TRANSMISSIVITY (ft^2/day)


ROSEBUD MINE SPOILS
TDS (mg/l)
100
1000
10000
0
50
100
150
200
250
300
TRANSMISSIVITY (ft^2/day)